DEVELOPMENTS IN INJECTION MOULDING—1

THE DEVELOPMENTS SERIES

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PREFACE

Injection moulding is the most important moulding process used by the plastics industry and some idea of its importance can be obtained by considering the following figures. The value of the UK market for plastics processing equipment was £60 million in 1977. Of this sum, £23 million was spent on injection moulding machines, that is, 40 % of all the money spent on plastics processing equipment in the UK.

It has been estimated that one-third of all plastics materials are processed by injection moulding. At the present time the process is of greater importance to the thermoplastics industry but its relevance to the thermoset industry should not be ignored.

Most of the equipment now used is based on single-screw pre-plasticising units. Once these machines had become established, in the 1960s, it was felt that the ultimate had been reached in machine design and utilisation. However, since that time, machines, processes and materials have undergone extensive development to make injection moulding safer, more reliable, easier to use and more economical to operate.

The purpose of this book is to review some of the developments that have taken place in this very important area. These developments are described by specialists in the field, who have extensive industrial experience and whose contribution will therefore be of immediate relevance to those concerned with the usage and application of this, the most important plastics moulding process.

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CONTENTS

Chapter 1

DIGITAL HYDRAULICS

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SUMMARY

The production cycle of an injection moulding machine, with its rapidly changing hydraulic energy requirements, calls for the use of the most modern industrial hydraulic equipment. In recent years a number of systems have become available which aim at improving the moulding process so as to give higher levels of automation and improved part quality. However, some of these systems are expensive and difficult to use.

A hydraulic system that provides ease of setting and gives good reproducibility (and has become known as digital hydraulics) will be described in this chapter.

1 INTRODUCTION

The production cycle of an injection moulding machine with its rapidly changing hydraulic energy requirements calls for the use of the most modern industrial hydraulic equipment. In this type of machine, production and process requirements must be met using the least possible space, and the machines must also be capable of being serviced easily. In addition they must be environmentally acceptable and economical in operation.

In contrast to continuous processes, which can often be optimised with the aid of fairly simple control systems, discontinuous production processes require the use of complicated and costly control techniques. At the beginning of the 1970s, a number of stratagems were known which helped to raise the injection moulding process to a higher level of automation and improved the quality of the product. In particular, the following had become necessary or available:

(i) devices which enabled individual process parameters to be adjusted or controlled upon the occurrence of interference factors;
(ii) mechanical or electrical storage of machine parameters, found to have been the optimum, which enabled such machine settings to be re-established in a reproducible manner;
(iii) the use of process computers as automatic start-up aids and for optimising production;
(iv) variation of individual parameters (e.g. injection speed and pressure) dependent upon distance or time, during the process cycle, as a method of effecting control and adjustment; and
(v) elimination of interference factors which affect the mechanical, hydraulic and electrical settings, i.e. improvements in the setting accuracy and reproducibility of a machine.

Whereas some of the above-mentioned stratagems can be practised only with great difficulty, improvements in machine control are acquiring increasing importance. Apart from the achievement of greater capacities (e.g. higher shot weights) and higher running speeds, successful efforts have been made to eliminate interferences that adversely affect the running of the machine on a reproducible basis. The most economical—though not always the most scientific—approach is by way of a fundamental analysis of the interference factors so as to eliminate the causes of interference at source. The choice of the methods applied and their quality and robustness determine the success of this stratagem.

A hydraulic system that provides ease of setting and gives good reproducibility (which has become known as digital hydraulics) will be described in later sections. However, let us first consider some of the various hydraulic systems that have been used with injection moulding machines.

2 CONTROL OF HYDRAULICALLY OPERATED INJECTION MOULDING MACHINES

Many different types of hydraulic component are available and such components may be connected together in numerous ways. Some of the systems used on injection moulding machines will be illustrated by reference to block circuit diagrams.

As initially stated, economics plays a big part in the choice of a particular system but other factors (such as, for example, the need for independent operation of some machine functions, machine noise, low installed power, etc.), must also be considered before a particular system is chosen.[1]

2.1 Single Pump Machines

The block circuit diagrams in Fig. 1 illustrate the various items which are necessary to establish the control chain for pressure, direction and speed

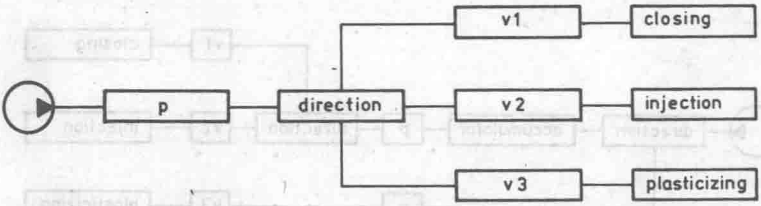

FIG. 1(a). Conventional circuit with separate means of speed control.

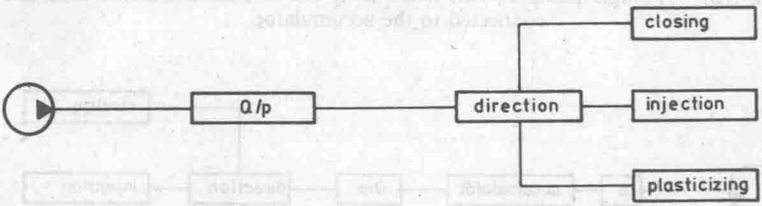

FIG. 1(b). Programmable circuit using a pressure–volume (Q/p) control device.

when the system is operated by means of only one fixed-volume pump. The usual sequence is illustrated in Fig. 1(a). The block marked 'p' represents a pressure control device, that marked 'direction' represents a switching unit or valve and those marked 'v' represent speed or volume control devices. For controlling speed, use is made of throttle valves, and, when the requirements are stringent, flow control valves are used.

If speed and pressure are to be programmable, a unit (marked Q/p in Fig. 1) for electrically controlling the amount and pressure of the oil delivered is arranged in front of the direction control device as shown in Fig. 1(b). This results in a very compact control system.

2.2 Machines with Accumulators

The pump capacity to be installed can be reduced with the aid of hydraulic

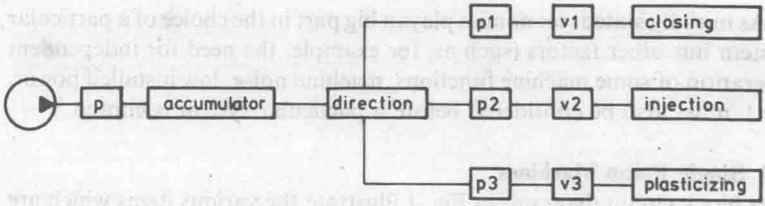

FIG. 2(a). Block diagram of single pump, accumulator circuit.

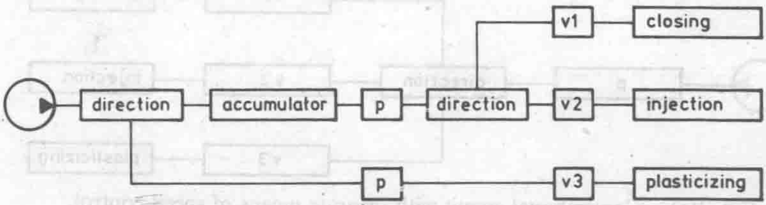

FIG. 2(b). A single pump curcuit where only the maximum element units are connected to the accumulator.

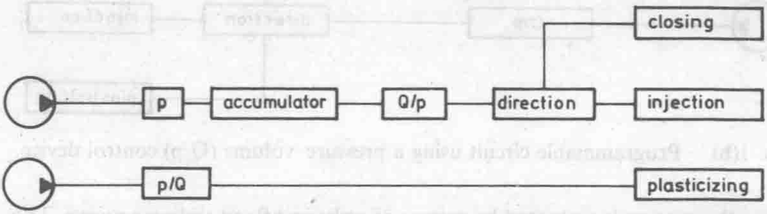

FIG. 2(c). Accumulator circuits with pressure–volume control device; plasticising with separate pump.

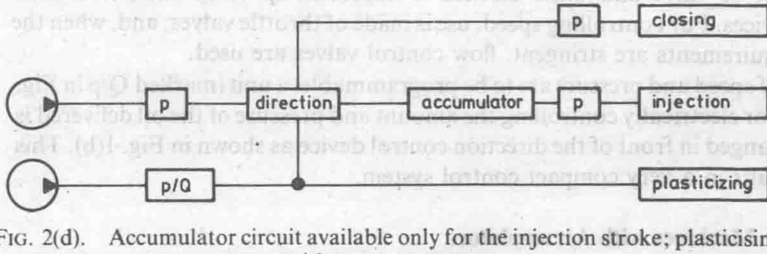

FIG. 2(d). Accumulator circuit available only for the injection stroke; plasticising with separate pump.

accumulators; this may be desirable if the hydraulic consumer units have greatly different requirements and if sufficient charging time is available.

With accumulator operation, as illustrated in Fig. 2(a), a difference occurs between the pressure built up in the accumulator and the particular working resistance that is required. The product of the pressure difference and the delivered flow of oil is a measure of the power loss caused by the accumulator. To keep power losses low, consumer units having a uniform oil requirement should be supplied directly from a pump. Proposal 2(b) shows how pressure accumulators are used for supplying those hydraulic units which have peak requirements. This is often only necessary in the injection operation.

The block circuit diagrams in Figs. 2(c) and (d) represent solutions using an additional pump for the hydraulic screw drive; pressure and speed are programmable for the hydraulic screw drive in the plasticising operation.

2.3 Multiple Pump Machines

The block circuit diagrams in Fig. 3 illustrate various means of controlling a system with multiple pumps. Solution 3(a) is the most frequently used scheme and is characterised by two pump circuits. Although one of these is,

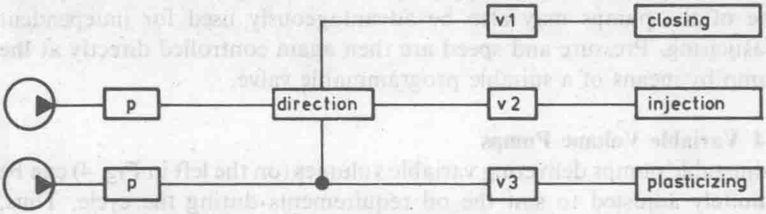

FIG. 3(a). Circuit with double pumps.

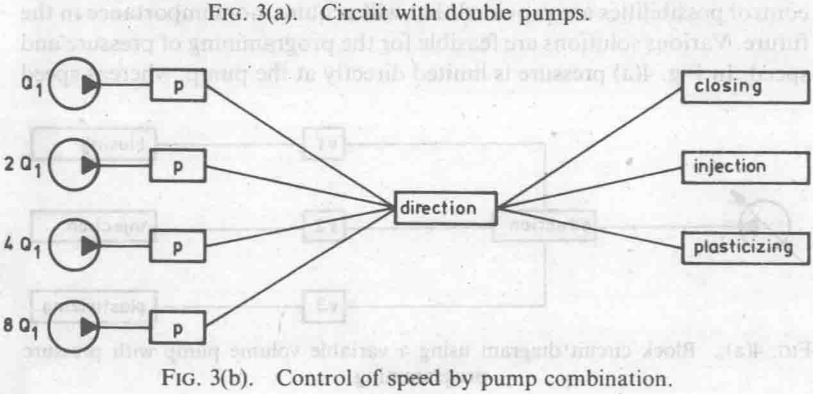

FIG. 3(b). Control of speed by pump combination.

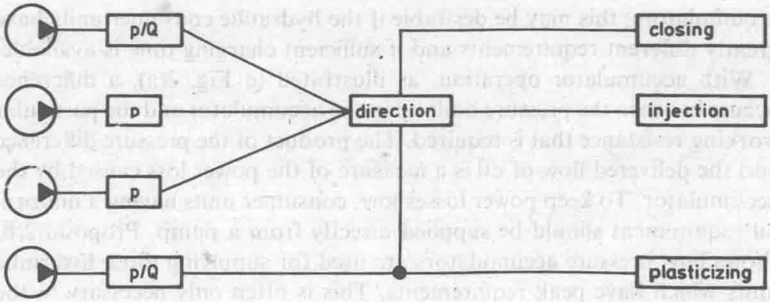

FIG. 3(c). Multiple pump system with separate pump for plasticising.

however, primarily used for supplying the hydraulic screw drive (plasticising) during injection, it is also connected up to the other pump to increase the injection speed.

With the aid of geometrically stepped delivered quantities from several fixed-volume pumps, speed can be controlled very economically. The example illustrated in Fig. 3(b) shows how, by means of electric controls, four different pumps, each giving a fixed volume, can be combined to achieve 15 different evenly stepped speeds. Naturally, as shown in Fig. 3(c), one of the pumps may also be advantageously used for independent plasticising. Pressure and speed are then again controlled directly at the pump by means of a suitable programmable valve.

2.4 Variable Volume Pumps

Adjustable pumps delivering variable volumes (on the left in Fig. 4) can be infinitely adjusted to suit the oil requirements during the cycle. Thus, control possibilities are provided that will acquire more importance in the future. Various solutions are feasible for the programming of pressure and speed. In Fig. 4(a) pressure is limited directly at the pump, whereas speed

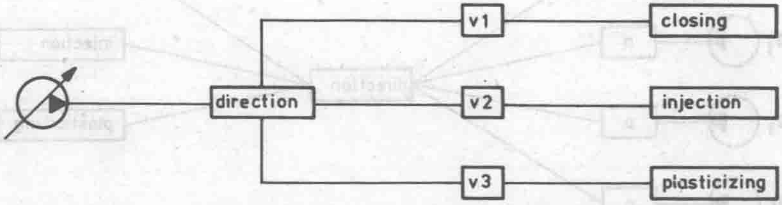

FIG. 4(a). Block circuit diagram using a variable volume pump with pressure programming.

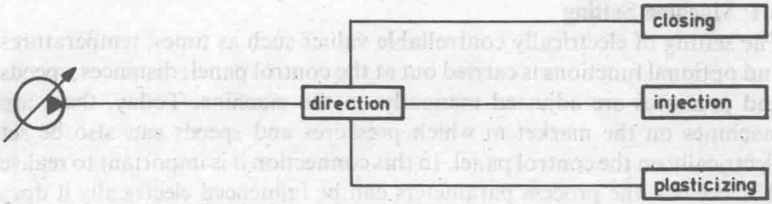

FIG. 4(b). Variable pump with speed and pressure programming.

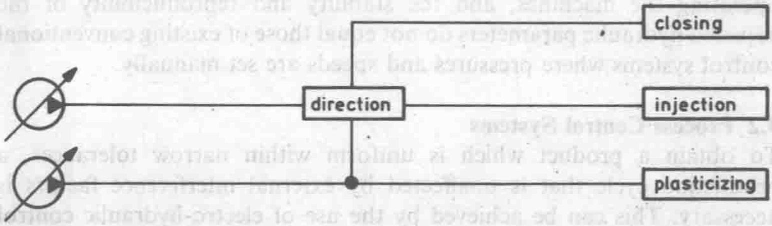

FIG. 4(c). Double pump with pressure and volume programming.

(e.g. injection speed) is set with the aid of throttle valves or volume regulators. The automatic regulation of the pump, when the required speed and the pre-programmed pressure are reached, enables the power requirements to be reduced compared with those occurring when fixed delivery pumps are used. In the variant shown in Fig. 4(b), speed programming is carried out directly at the pump. Manually adjustable throttle valves are replaced by electrically set controls. In this system priority is given to the speed setting, so that the pump only has to deliver against the particular operating pressure. This system cannot be bettered as regards power requirements. For the sake of completeness, Fig. 4(c) again shows the extension of the drive for independent plasticising using a further regulating pump.

3 METHODS OF IMPROVING MACHINE PERFORMANCE

The development of hydraulic control systems for injection moulding machines is characterised by a trend towards progressively better performance. Such a trend is accompanied by requirements for smaller sized units, smoother running systems, an increased number of functions, and greater operational reliability.

3.1 Machine Setting

The setting of electrically controllable values such as times, temperatures and optional functions is carried out at the control panel; distances, speeds and pressures are adjusted manually on the machine. Today, there are machines on the market in which pressures and speeds can also be set electrically on the control panel. In this connection it is important to realise that because the process parameters can be influenced electrically it does not always automatically follow that improved reproducibility results.[2] Certain variants of this technique simply result in greater convenience in operating the machines, and the stability and reproducibility of the adjusted hydraulic parameters do not equal those of existing conventional control systems where pressures and speeds are set manually.

3.2 Process Control Systems

To obtain a product which is uniform within narrow tolerances, a production cycle that is unaffected by external interference factors is necessary. This can be achieved by the use of electrc-hydraulic control circuits consisting of a servo valve, an actual value sensor (or transducer), and the associated control electronics. Such systems, commonly known as process control systems, take care of the injection operation in particular and, within certain limits, they are capable of offsetting the effects of temperature fluctuations e.g. fluctuation of tool, melt and oil temperatures. However, a measurable increase in quality can also be achieved in machines using simple conventional control systems.

Practice has shown that the complicated techniques involved in process control systems—contrary to the reasons often put forward in their favour—require operating personnel who are trained in control techniques and in the operation of the production process. These requirements are not met in the great majority of companies concerned with injection moulding. Most processing firms require machines having hydraulic and electrical control systems that are capable of eliminating interference factors which might influence the reproducibility of the production process; in this way they avoid the need for using complex control systems.

3.3 Control of Oil Temperature

In addition to the temperature of the tool, the temperature of the oil of the hydraulic system has a decisive influence on the reproducibility of the production cycle. If the oil temperature and therefore its viscosity (Fig. 5) are kept constant, then conventional hydraulic equipment operates in an astonishingly constant manner over lengthy production periods.

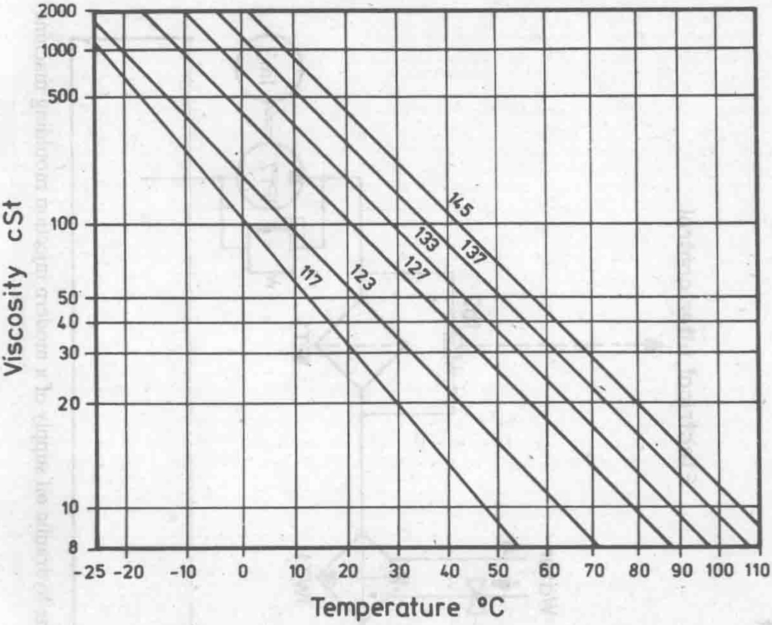

FIG. 5. Viscosity–temperature graph for some hydraulic oils.

Preheating of the oil drastically shortens the start-up phase, so that correction of the machine settings becomes unnecessary.

Figure 6 illustrates one form of preheating and control circuit for the oil of the hydraulic system. The oil is heated up with the aid of hydraulic pumps and pressure valves not illustrated in the figure. A heat sensor communicates the actual value of the temperature to an electronic on–off controller which in turn acts on a (digital) water valve. In this way a variation in oil temperature is achieved that oscillates between two very close limiting values and is independent of the machine cycle that has been set (Fig. 7).

3.4 Digital Systems and Cartridges

With the aid of new digital systems for controlling pressure and speed it is possible to achieve ease of operation of the machine together with high setting precision.

With increasingly higher operating speeds more attention is again being directed towards the switching times of hydraulic multi-way valves. This